

Charge Your Cell Phone in Your Pocket

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Wireless Charging

Today: zero distance & highly sensitive to orientation



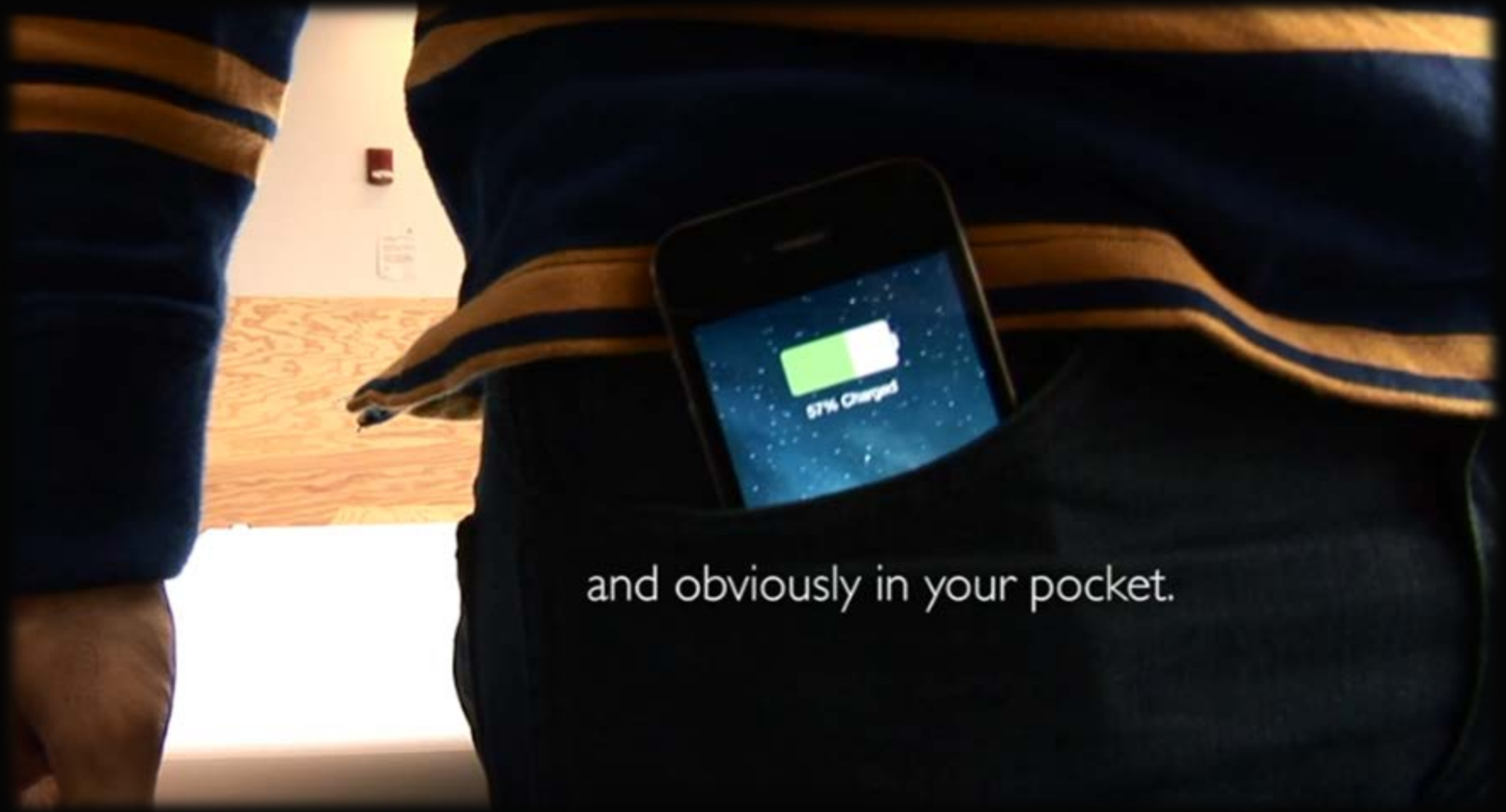
A small increase of charging distance and a flexible orientation → Big gain in user experience



A small increase of charging distance and a flexible orientation → Big gain in user experience



MagMIMO



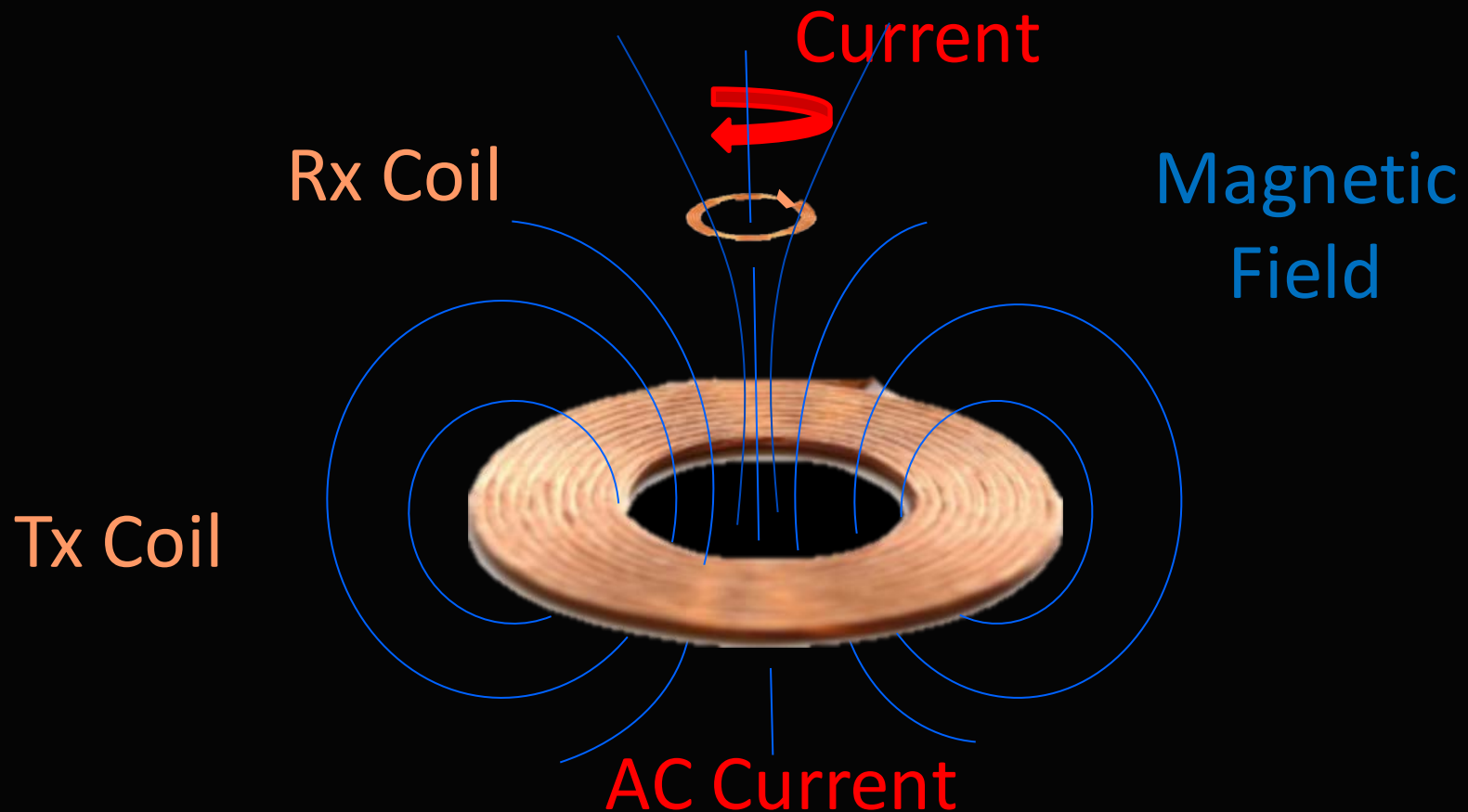
and obviously in your pocket.

How Does It Work?

Wireless Charging Primer

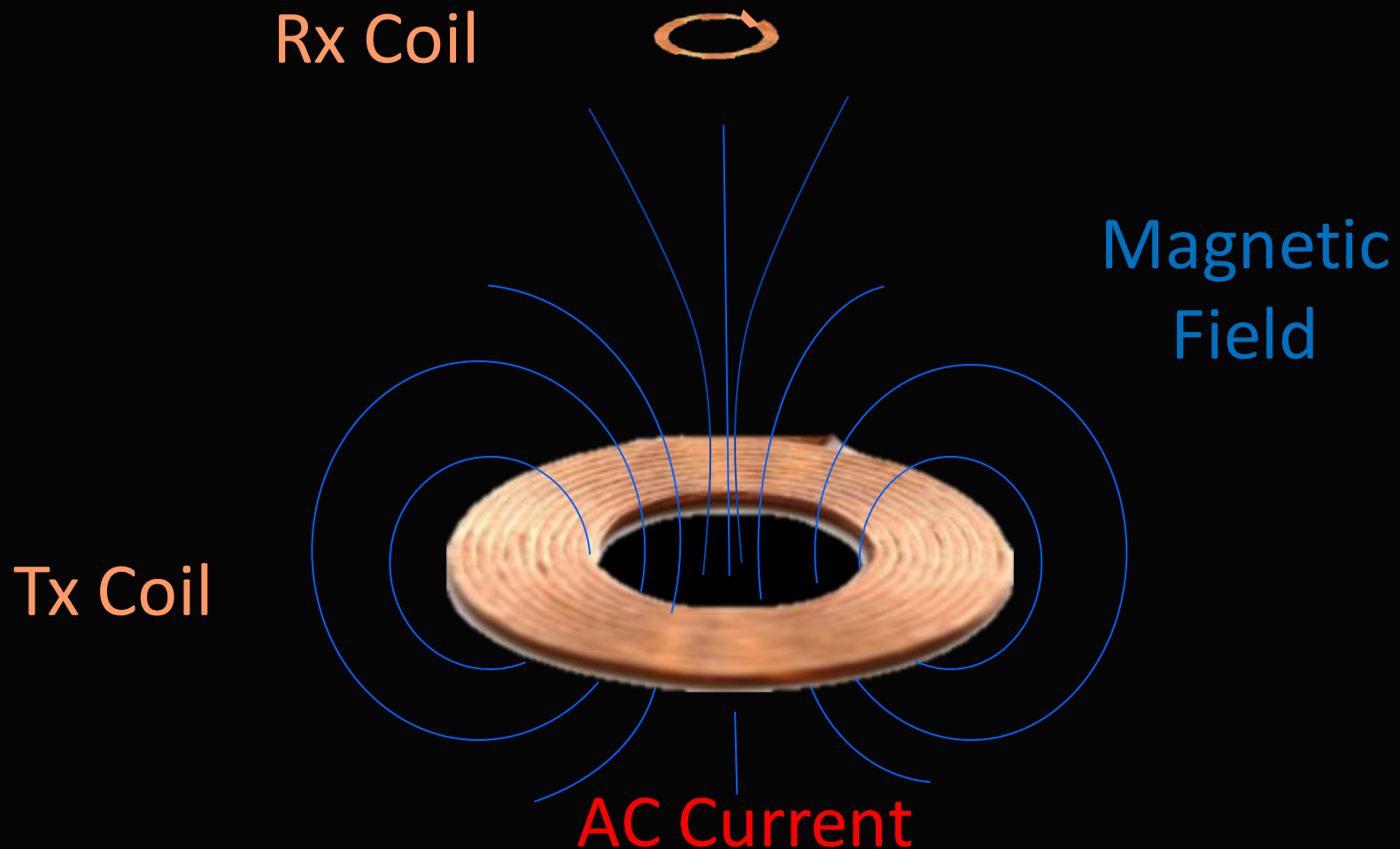
Wireless Charging Primer

Magnetic field generates a current in Rx \rightarrow Power in Rx



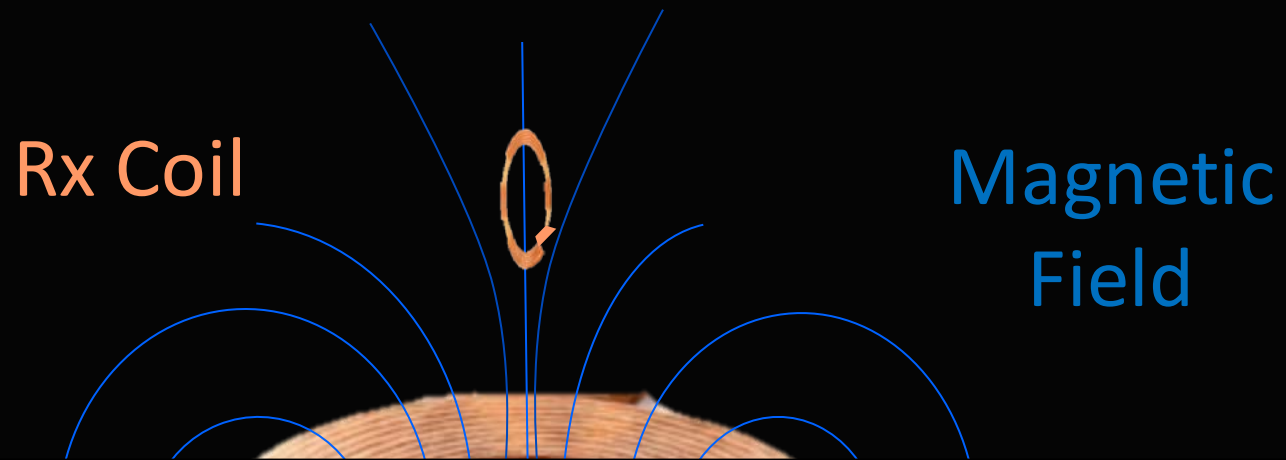
Wireless Charging Primer

Magnetic field doesn't cross Rx \rightarrow No Rx current



Wireless Charging Primer

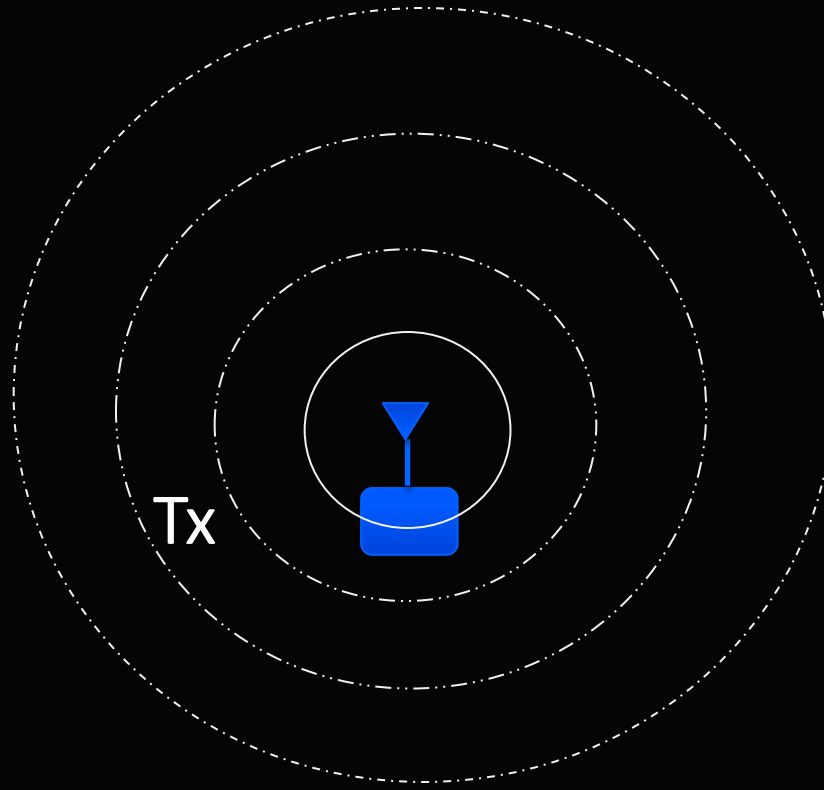
Magnetic field doesn't cross Rx \rightarrow No Rx current



\rightarrow Existing chargers fail with distance or orientation

Can We Borrow from Wireless Communications?

Rx  SNR too low \rightarrow no signal!



Can We Borrow from Wireless Communications?

Rx

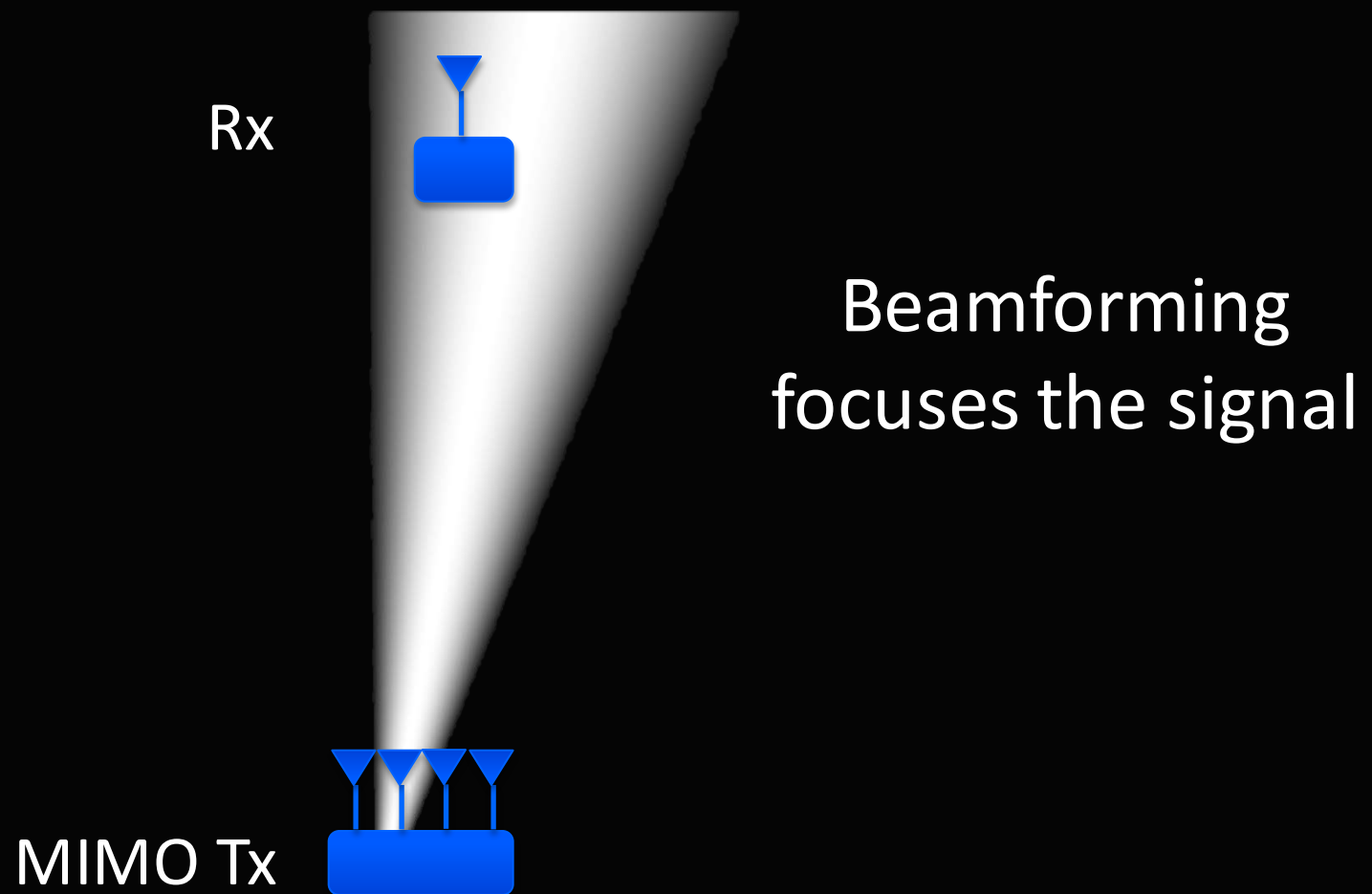


SNR too low \rightarrow no signal!

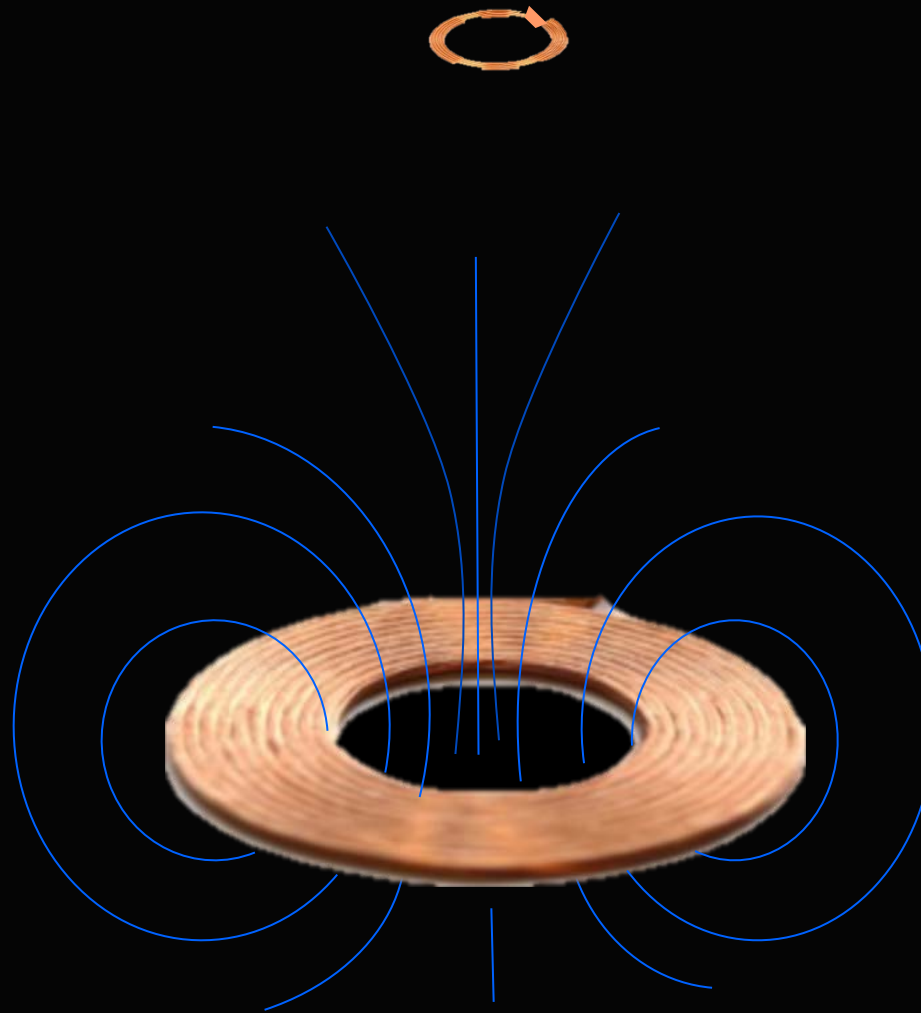
MIMO Tx



Can We Borrow from Wireless Communications?



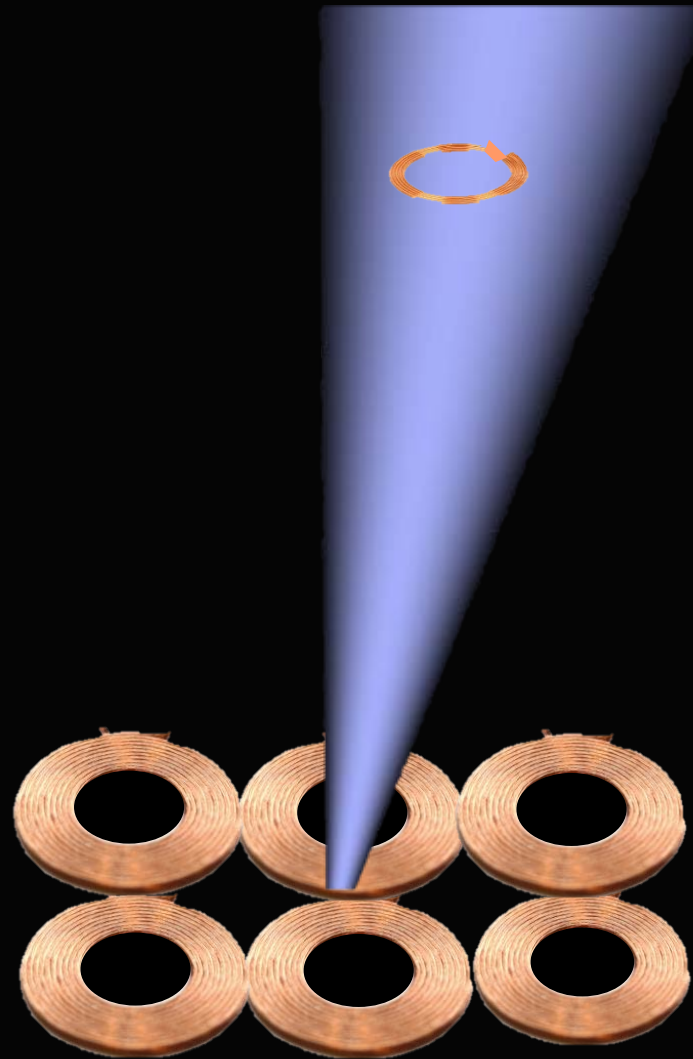
Can We Borrow from Wireless Communications?



Magnetic
Field

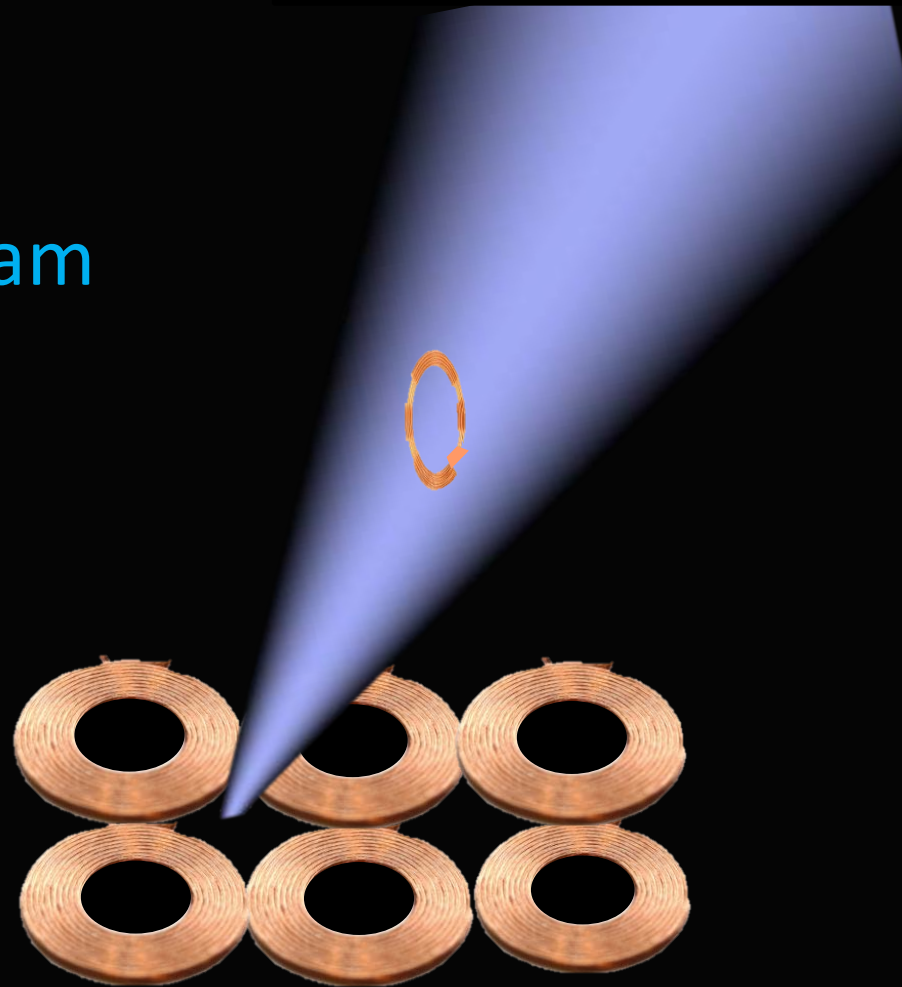
Can We Borrow from Wireless Communications?

Magnetic
Beamforming



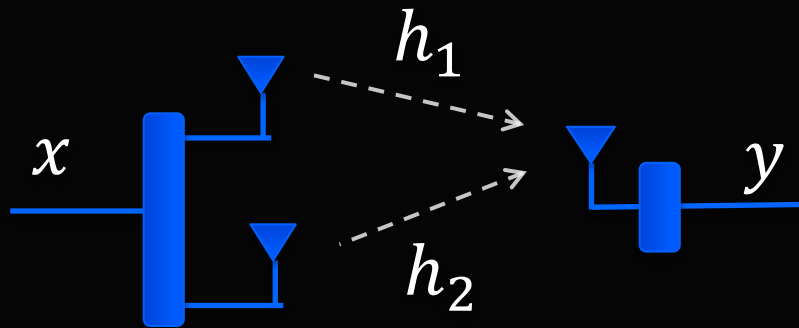
How Do We Beam-form the Magnetic Field?

Steer the beam
with Rx



Derivation of Magnetic Beamforming

Derivation of Magnetic Beamforming

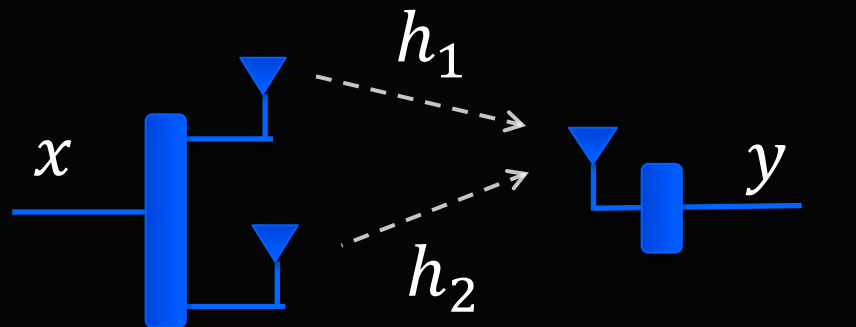


Tx symbol

$$y = (h_1 + h_2) x$$

Rx symbol

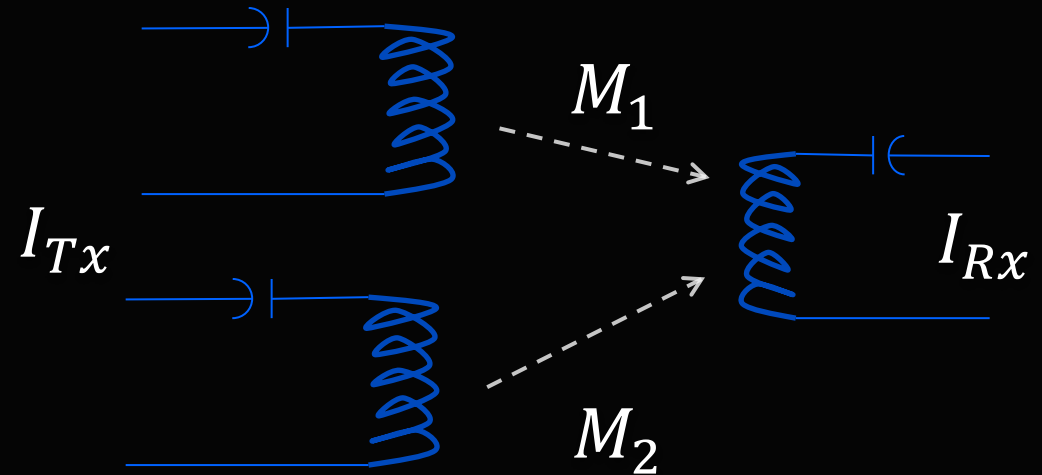
Derivation of Magnetic Beamforming



Tx symbol

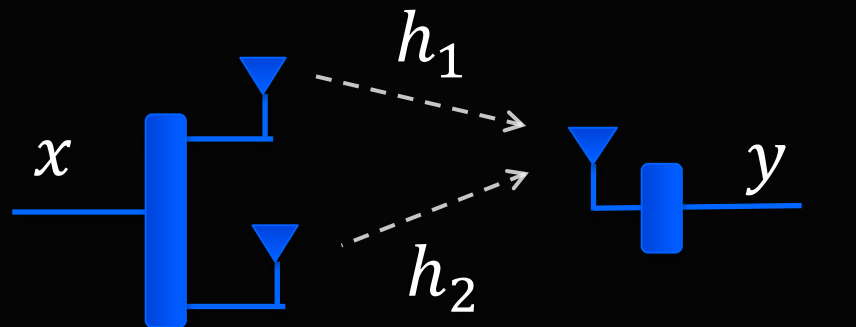
$$y = (h_1 + h_2) x$$

Rx symbol



$$I_{Rx} = C \cdot (M_1 + M_2) I_{Tx}$$

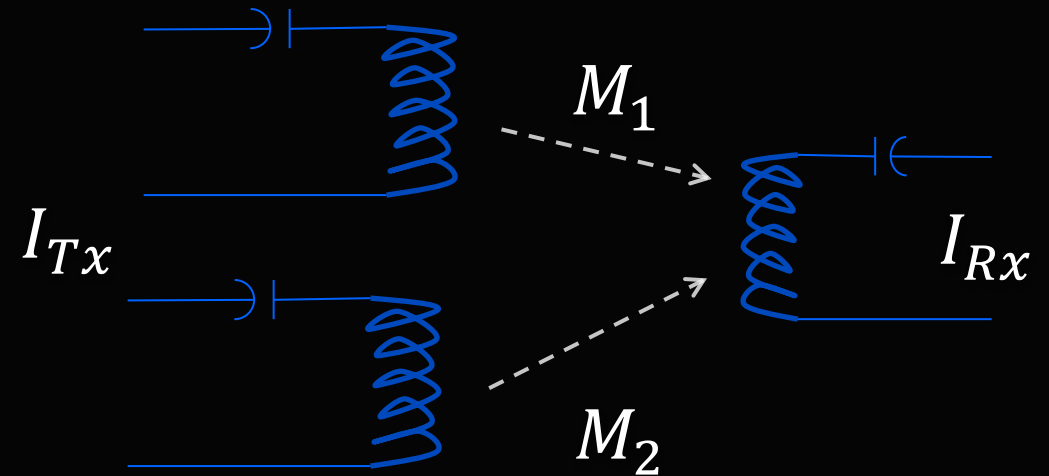
Derivation of Magnetic Beamforming



Tx symbol

$$y = (h_1 + h_2) x$$

Rx symbol



Tx current

$$I_{Rx} = C \cdot (M_1 + M_2) I_{Tx}$$

Rx current

Constant

Channels \rightarrow Magnetic Coupling
Symbols \rightarrow Currents



Same Mathematical Framework

Tx symbol

$$y = (h_1 + h_2) x$$

Rx symbol



M_2

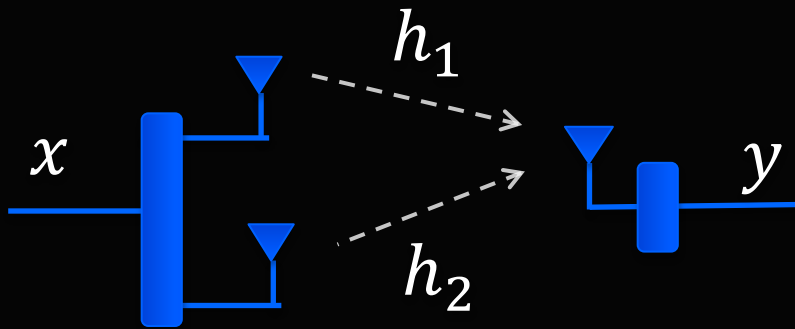
Tx current

$$I_{Rx} = C \cdot (M_1 + M_2) I_{Tx}$$

Rx current

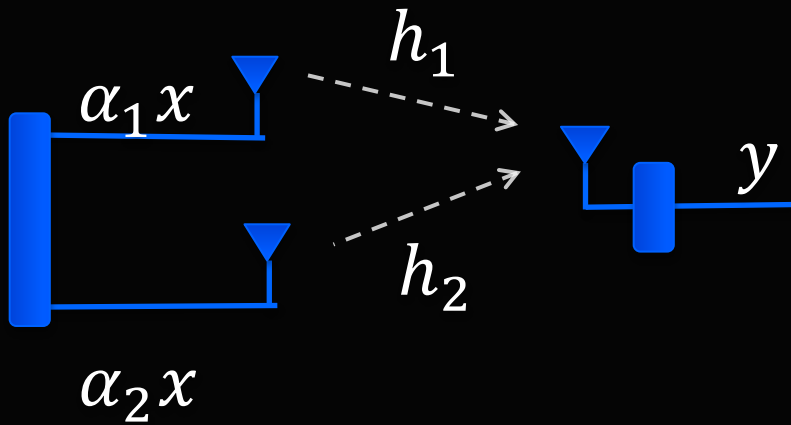
Beamforming

Beamforming



RF Beamforming

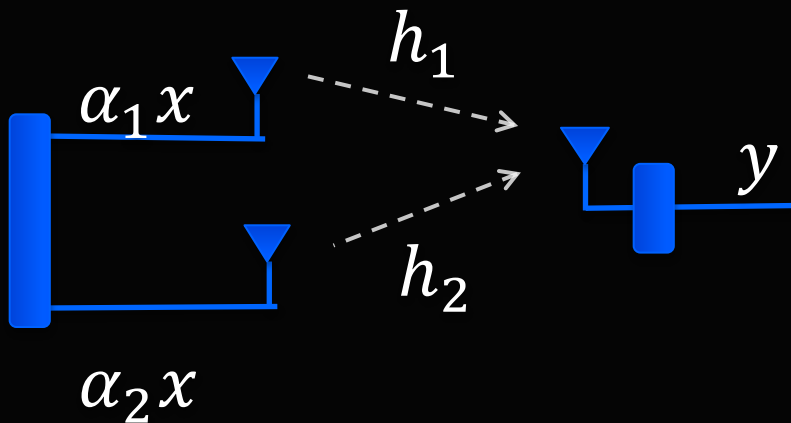
Beamforming



RF Beamforming

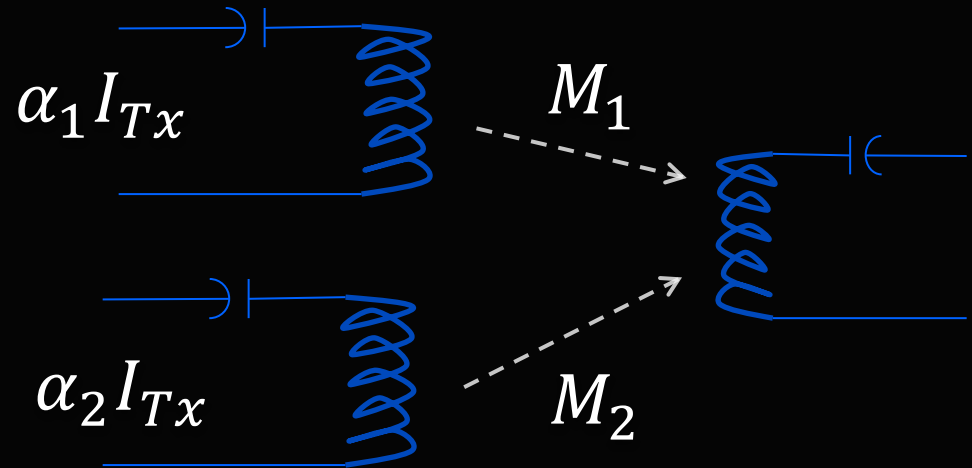
$$\alpha_i = \frac{h_i^*}{\sqrt{\sum |h_j|^2}}$$

Beamforming



RF Beamforming

$$\alpha_i = \frac{h_i^*}{\sqrt{\sum |h_j|^2}}$$



Magnetic Beamforming

$$\alpha_i = C' \frac{M_i^*}{\sqrt{\sum |M_j|^2}}$$

→ Shape the magnetic field in a beam

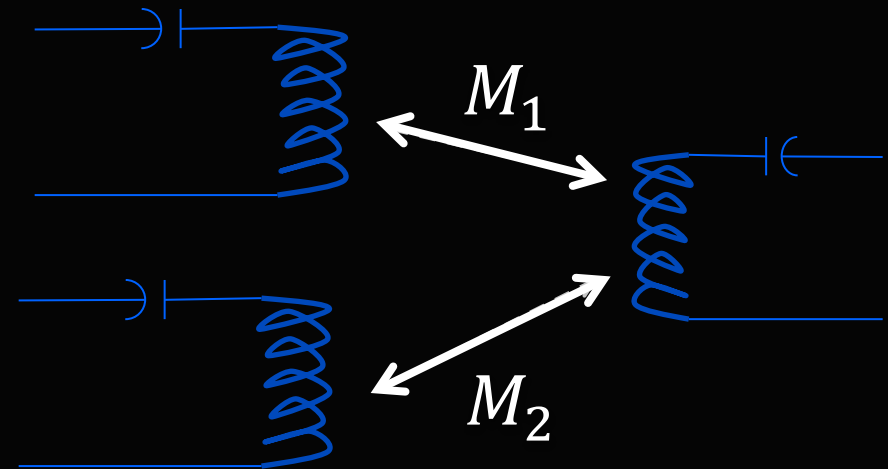
Are we done?

RF Beamforming

- Tx needs the channels, h_i , to compute α_i
- Rx measures the channels and send them to Tx

Magnetic Beamforming

- Tx needs the magnetic coupling, M_i , to compute α_i
- Rx is out of power \rightarrow Can't measure and send the M_i



Magnetic Coupling can be measured locally at the transmitter

Performance

Implemented MagMIMO

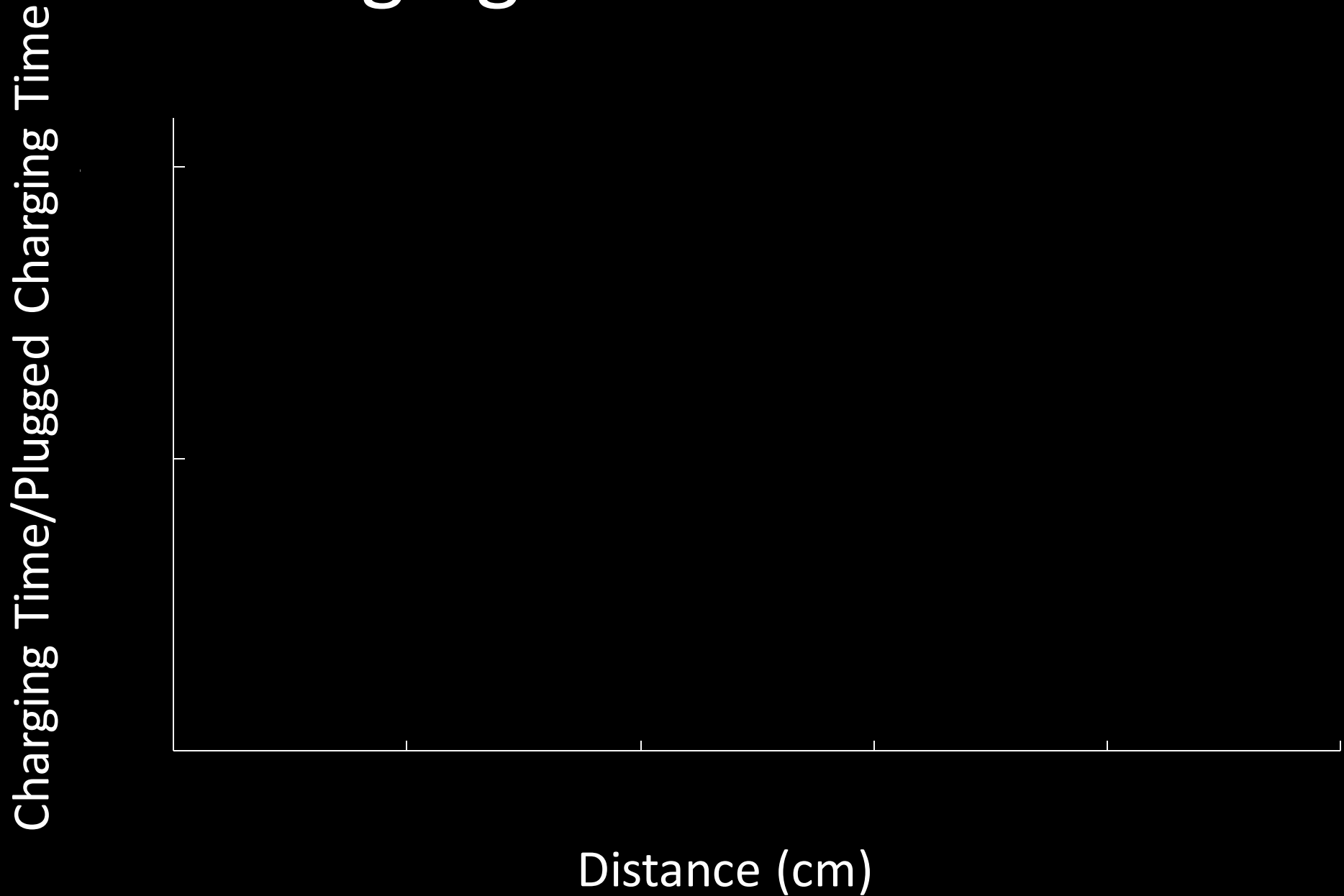
- 6 Tx coils controlled by programmable logic, which applies the beamforming multipliers to Tx currents
- Experimented with iPhone 4S



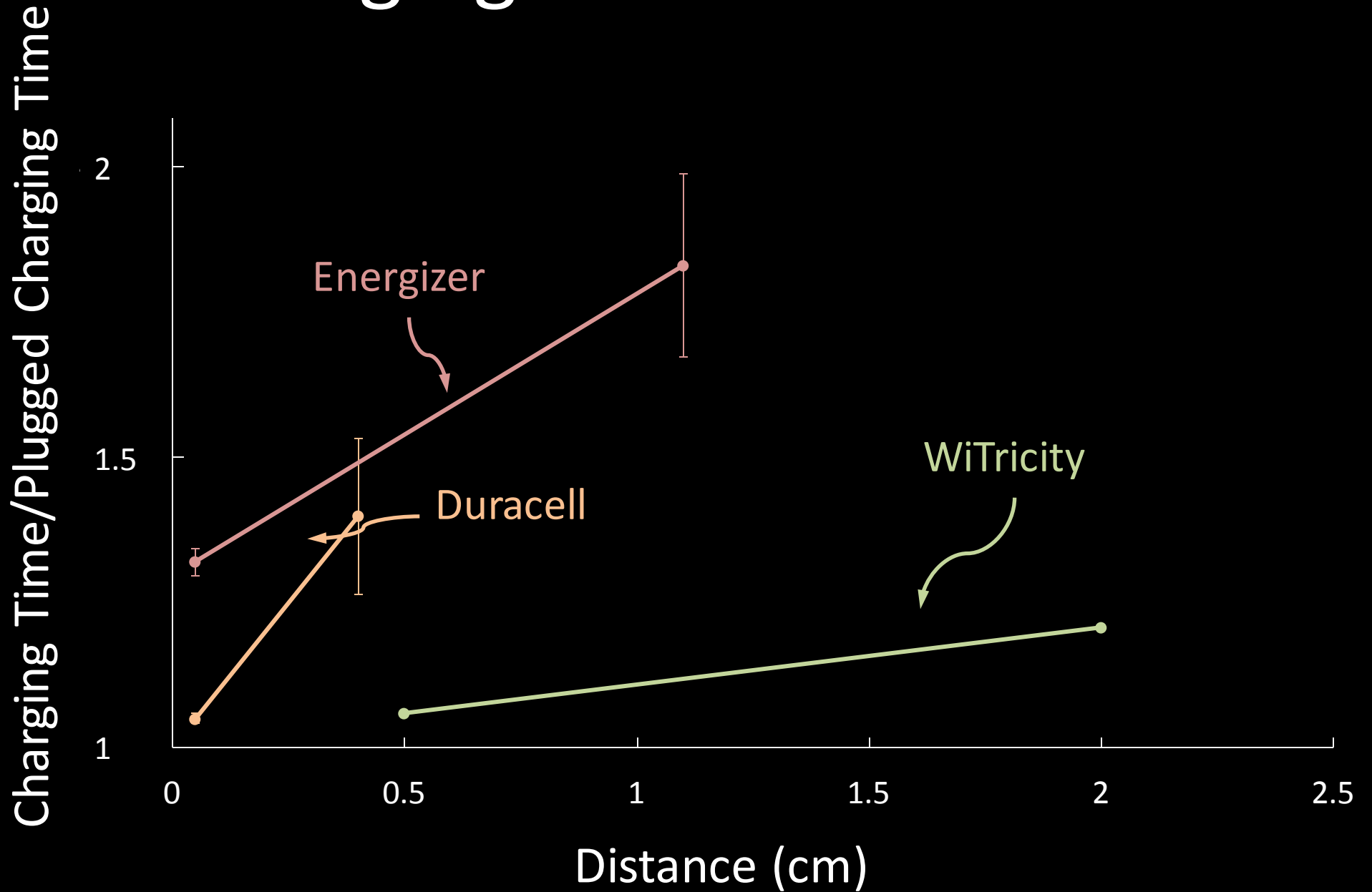
Compared Systems

System	Input Power
Witricity Wit-2000M	24 [W]
Energizer Qi	22 [W]
Duracell	18 [W]
MagMIMO	20 [W]

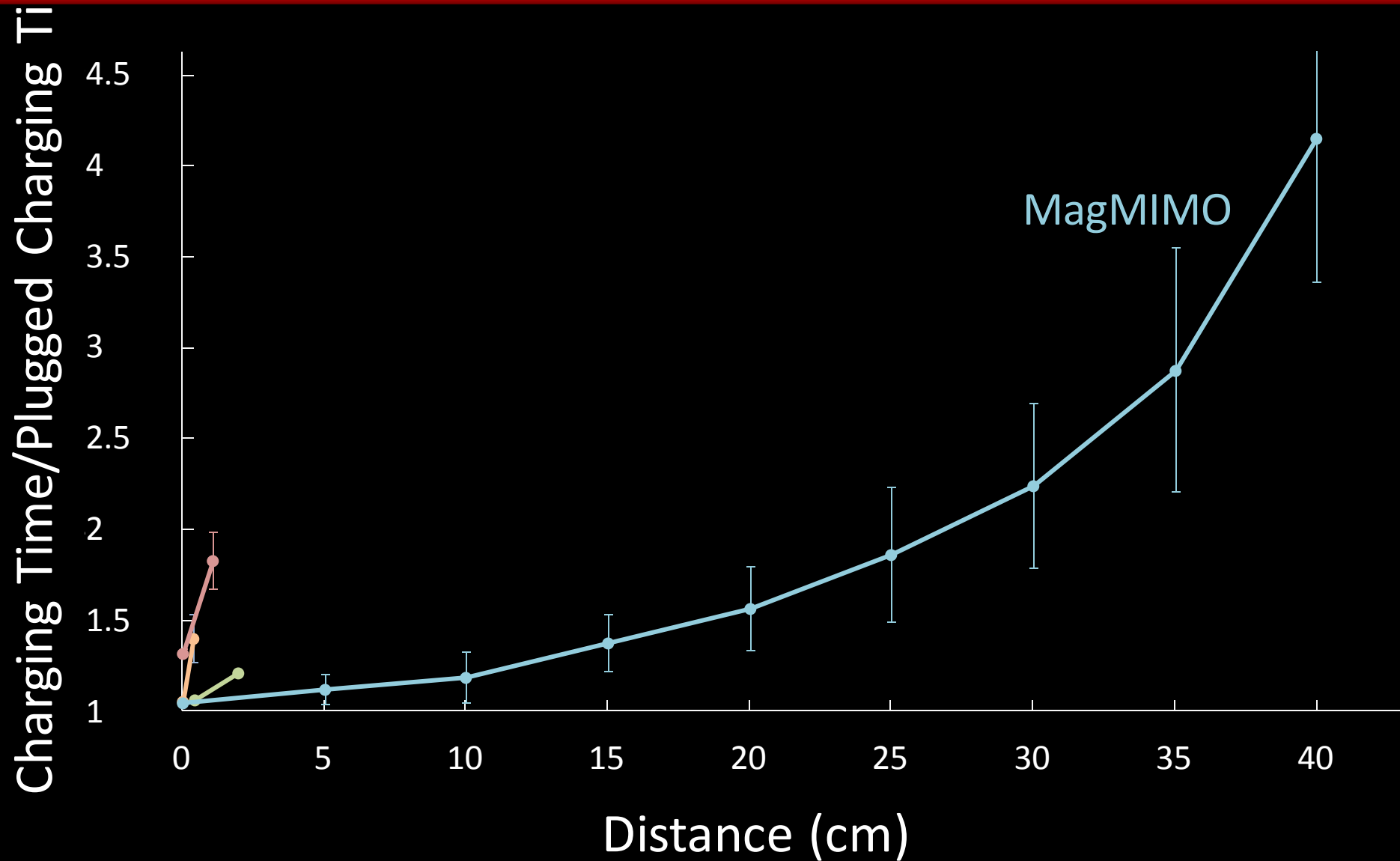
Charging Time vs. Distance



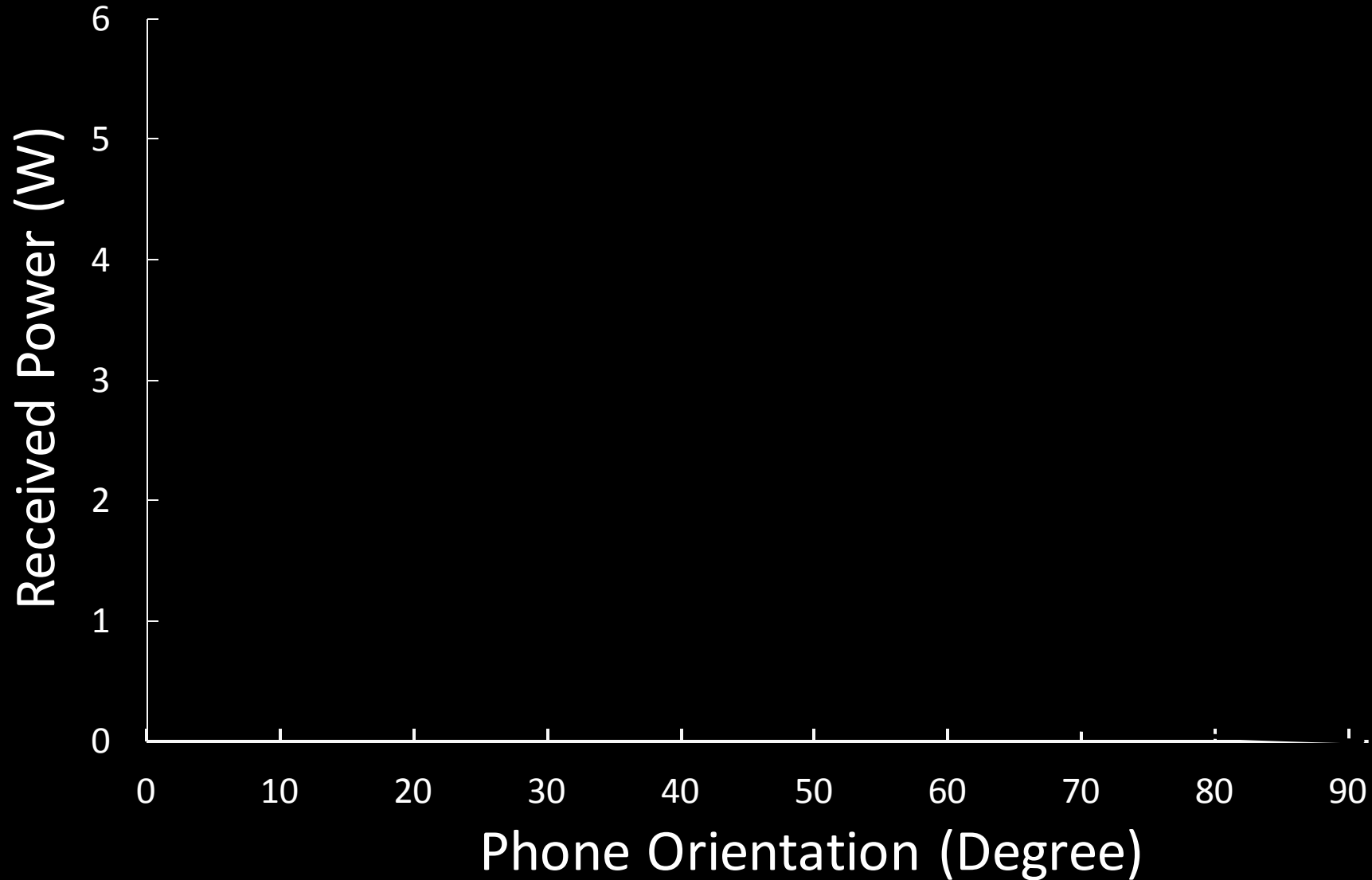
Charging Time vs. Distance



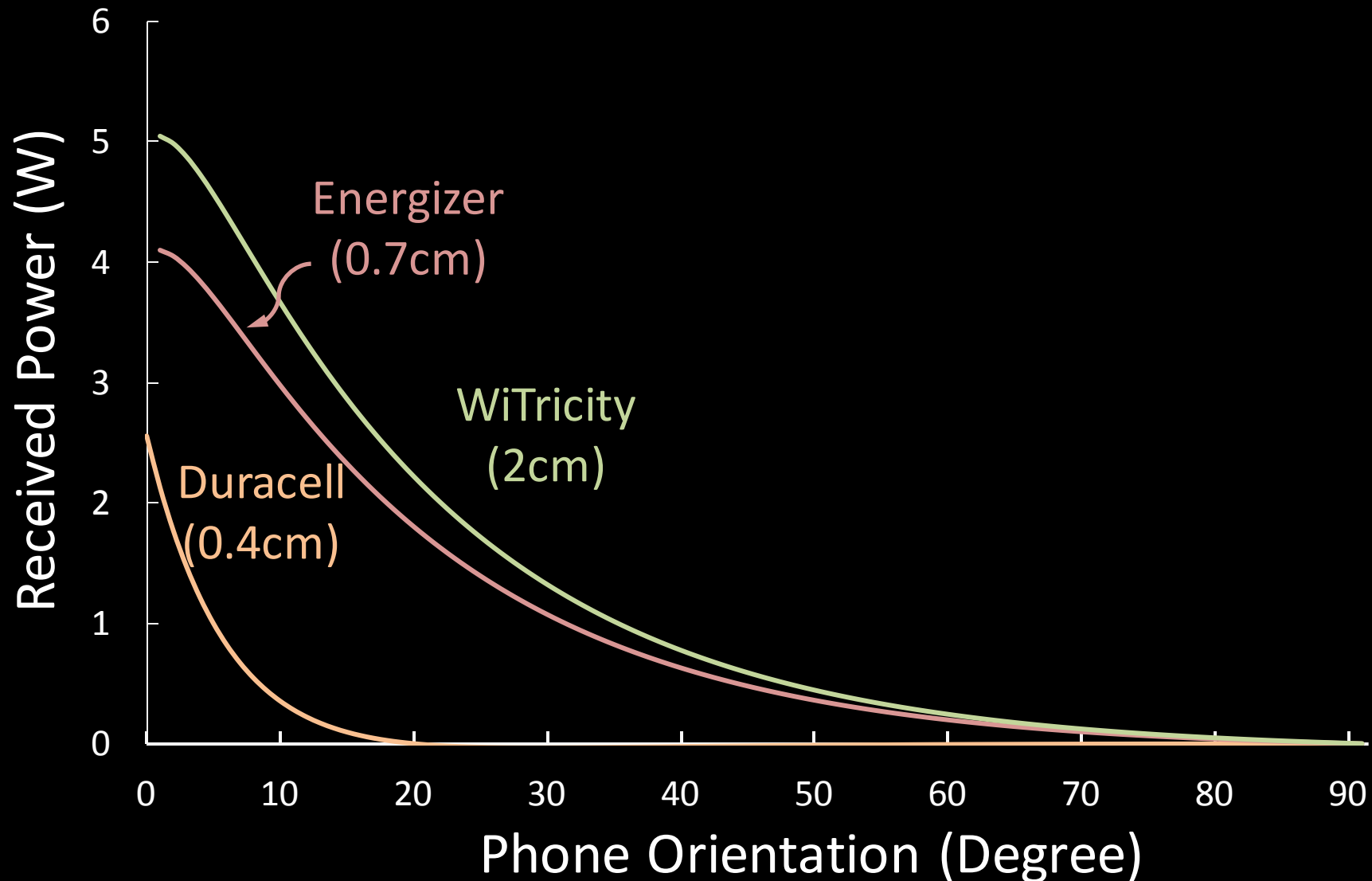
MagMIMO supports much longer distances



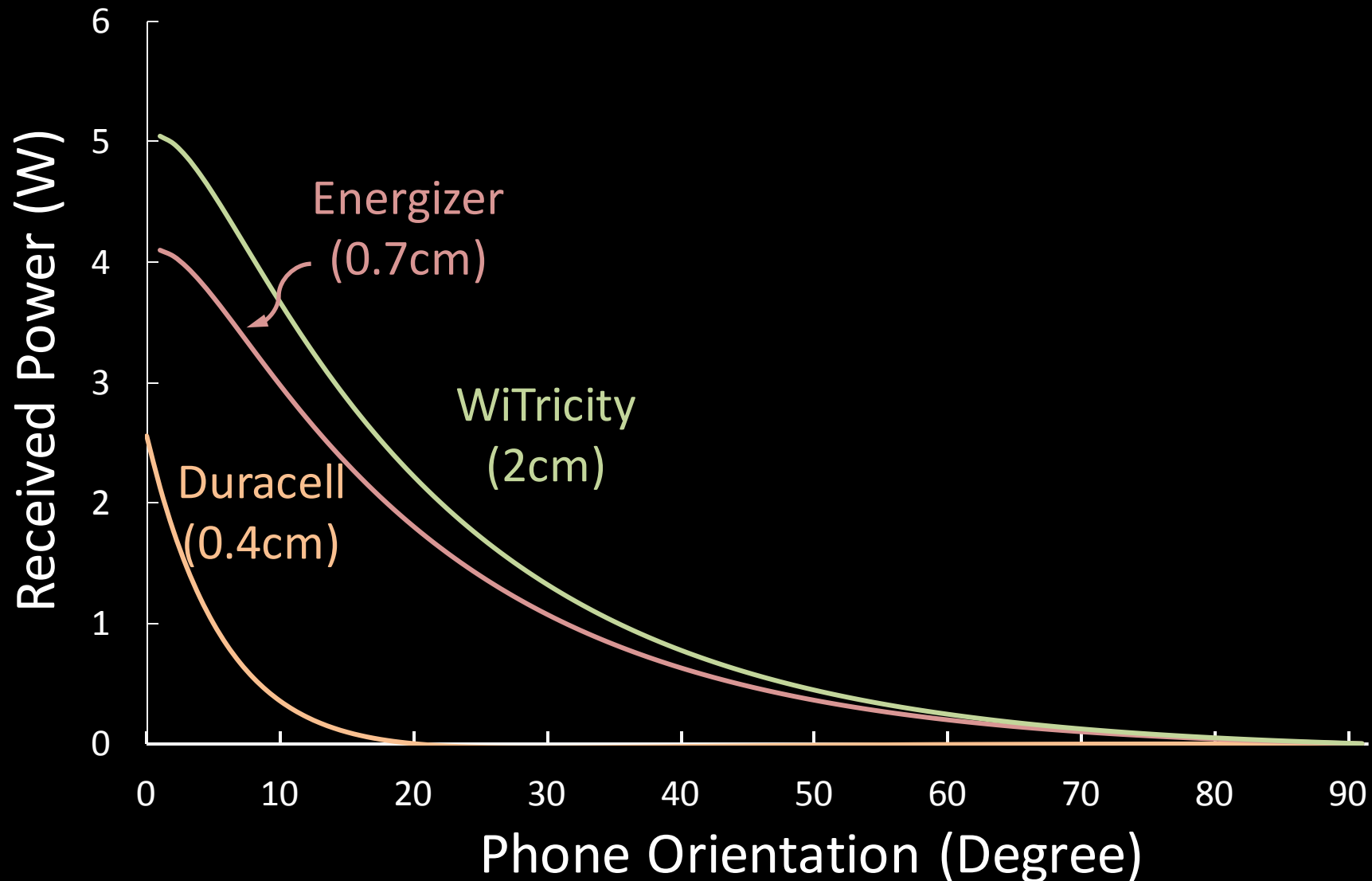
Dealing with Phone Orientation



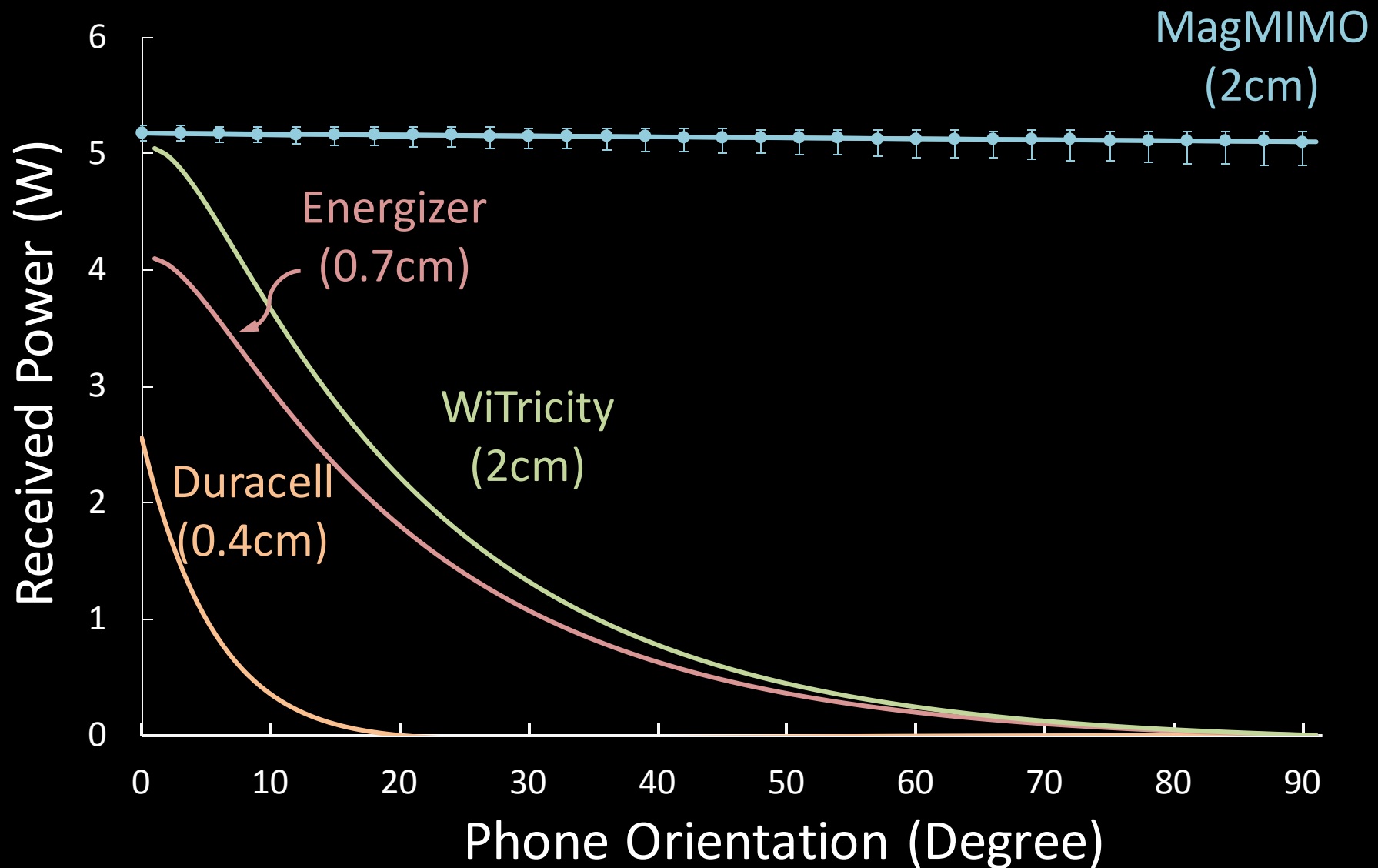
Dealing with Phone Orientation



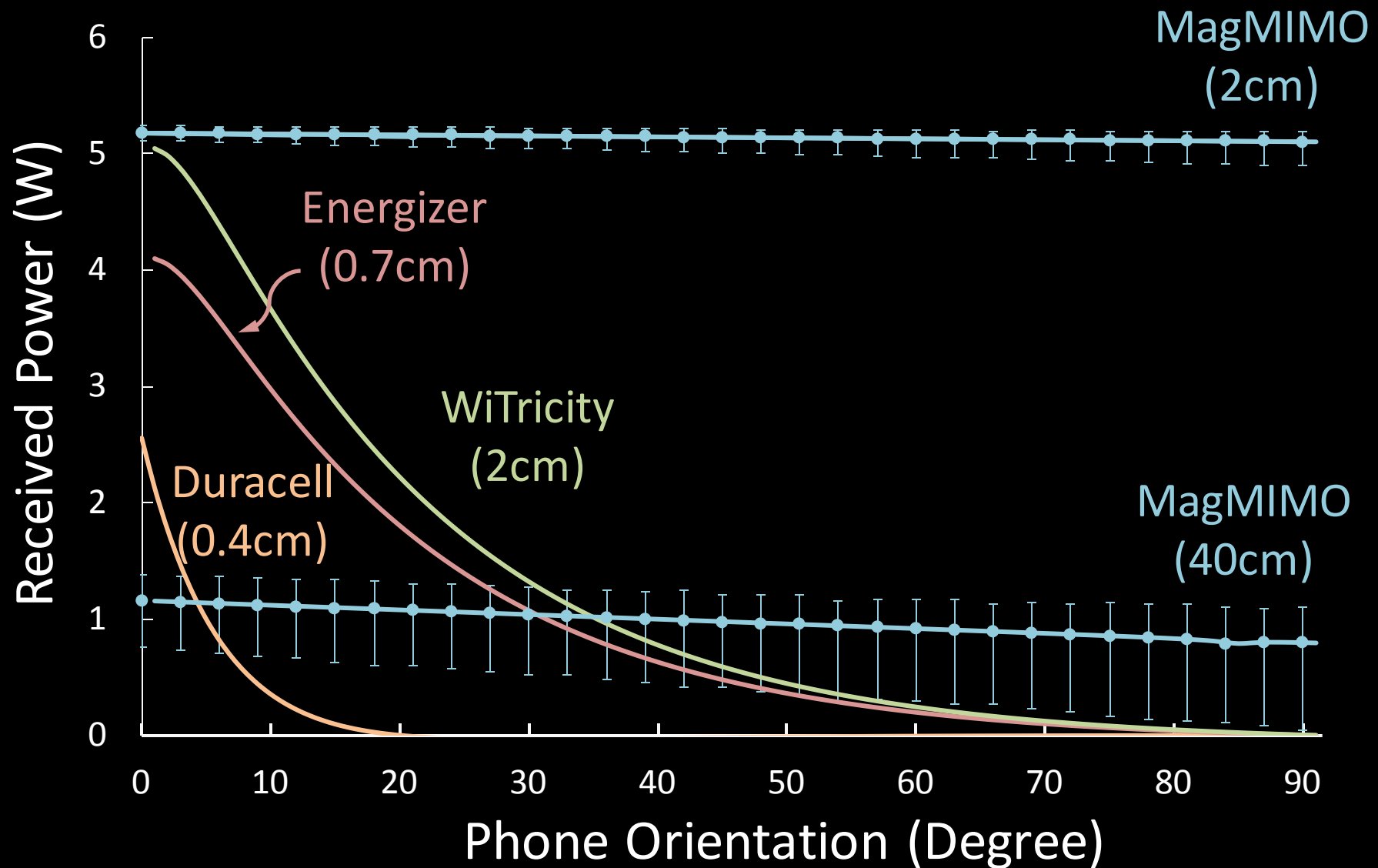
Dealing with Phone Orientation



Dealing with Phone Orientation

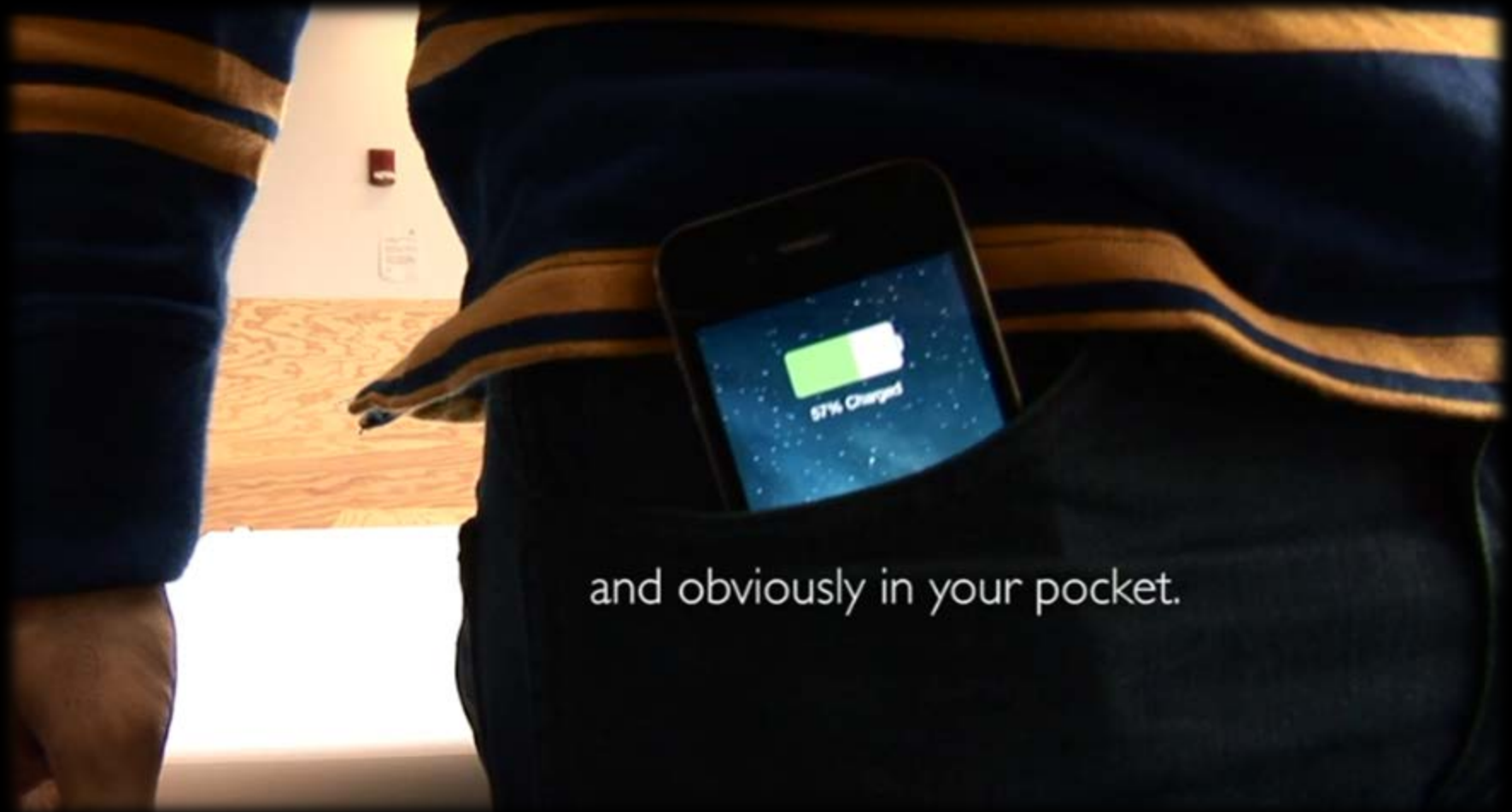


Dealing with Phone Orientation



Conclusion

- MagMIMO charges your phone in your pocket



and obviously in your pocket.

Conclusion

- MagMIMO charges your phone in your pocket
- Even more critical for wearables

